REVIEW OF CURRENT PRACTICE AND PROPOSALS FOR DEVELOPMENTS IN SMART DYNAMIC TESTING

1 Background and Formation of Smart Dynamic Testing Community of Practice
Phase I: to a Workshop November 2018 and Phase II: to Development of an Action Plan 2020

Origins, and first Meetings

A Community of Practice (CoP) was established early in 2018 to coordinate activities and interests in the new technology of Smart Dynamic Testing (SDT). This followed the successful development of a specific testing method, known as IMMAT, which yields dramatic improvements in quality and economy in full-scale industrial practice. Initial activities of this CoP group comprising some ~50 participants from ~30 government, industry and university organisations, focussed on two activities: (i) capturing the new SDT methodology in Best Practice Handbooks (for eventual revision at Standards level) and (ii) exploration for other types of dynamic test which might benefit from the 'Smart Testing' philosophy. A total of 12 meetings of the CoP have now taken place, mostly on-line but including significant face-to-face meetings at major conferences plus one 2-day dedicated Workshop.

Phase I – Leading up to the Residential Workshop in Arlington VA, November 2018

The residential Workshop was held at Arlington towards the end of 2018, sponsored by Virginia Tech, and was a major activity that helped to launch the CoP's raison d'etre. This was attended by 25 delegates including many of the most advanced dynamic testing practitioners in the USA and the UK. The focus at the Workshop was on defining specific activities for the CoP and the final plan was as follows:

Part 1 Compile and draft the contents of a Best Practice Handbook Document; and

Part 2 Develop ideas for strategic research and R&D to apply the SDT philosophy to as many types of dynamic testing as required by a wide range of industries in Aerospace and Defence.

For the first of these 2 Parts, considerable progress was made during the Workshop in defining the underlying technologies that form the basis of SDT, and these were presented as 4 themes which provide a well-defined structure for future development of new testing techniques and of their eventual documentation and reference. These Technology Themes were:

A. Test Specification: Environmental capture and definition;
B. Boundary Conditions and Fixture Design;
C. Excitation Strategy; and
D. Test Optimization and Integration

and their integration would serve to provide the 'smart' features across a whole range of dynamic test procedures of the whole concept. For the second Part, ideas for a strategic research program were discussed along with appropriate university – industry interfacing for this high TRL research activity.

Phase II – Survey of Current Dynamic Testing Practice and Plans for Future Developments of SDT

Following the Arlington 2018 Workshop, there was a significant contribution to the overall planning and formulation from two face-face meetings at IMAC2019 in Florida and at IMAC2020 in Houston. The initial idea of preparing best practice documentation turned to an alternative way of disseminating SDT technology by presenting short courses at meetings such as IMAC, and one such course has been designed for the next face-face opportunity. The major interest, however, now focuses on the prospects of developing several other formats of smart dynamic testing to follow IMMAT which is now becoming more widely used and delivering significant benefits to new users.

Thus, attention is now focussed on the task of formulating a Strategic Research Program based a detailed survey of industry's current practices and procedures of dynamic tests with a view to identifying and prioritising some of these for evolution into the domain of 'smart' dynamic tests. A Questionnaire has been prepared and distributed to all the members of the CoP with the invitation to share information about their test requirements, current capabilities and limitations, with a view to defining immediate research activities. This procedure has now completed its first cycle with contributions from 10 major users of Structural Dynamic Tests of all forms. The next phase is to compare all the practices and aspirations of these organisations and to devise a Strategic Research Program to lead to major technology developments in the future.

2. Proposed Areas for Fruitful Research in SDT (Tasks and Philosophy)

Structural Dynamics Testing (usually in the form of laboratory shock and vibration testing) has been performed for decades to qualify mechanical components and systems for life-cycle environments. The traditional laboratory tests and specifications have significant shortcomings for qualification of the unit under test (UUT). The Community of Practice for Smart Dynamic Testing (CoP for SDT) has identified major technologies for research in which Smart Dynamic Testing could reduce cost and schedule and increase reliability tremendously in the qualification of a UUT. The 3 prime technologies in need of research are:

1. **Traditional single-axis vibration testing;**
2. **Systematic Fixture Design to eliminate undesirable influence from inappropriate laboratory test fixturing; and**
3. **Traditional single-axis mechanical shock testing.**

Multiple technical flaws associated with traditional single axis dynamic testing require resolution in these technology areas. Perfect control of a single axis base input accelerometer does not reproduce the field failure modes since the orthogonal base accelerations and rotations are artificially constrained to zero; the field failure modes must be technically addressed in the laboratory simulation. A single enveloped base acceleration input is even worse, as this often results in order-of-magnitude over-responses at extremities of the UUT at the laboratory fixed-base frequencies and similar under-response at other frequencies. Combinations of fixture resonances and boundary conditions often excite failure modes and stress amplitudes that are not encountered in the field environment. The damaging response of the field life cycle environment is not quantifiably related to the laboratory base input and boundary conditions. The prime technology research areas could yield massive improvements in development costs, scheduling and reliability.

One member of the CoP provided the following definition of Smart Dynamic Testing: *"a technical basis that increases reliability while decreasing cost, schedule and risk"*. The principles for SDT require research to develop a technical basis to address the 3 prime technology research areas listed above. These principles are:

(i) Designate a damage metric to define the field requirement;
(ii) Obtain and locate enough field response data to approximate the damage metric;
(iii) Determine appropriate fixturing and excitation for the laboratory test;
(iv) Provide appropriate control responses to emulate the field damage metrics.

These principles utilize reduced-order models to provide the appropriate optimization and control through virtual testing. Such models may be analytical and/or test-based. The CoP noted that in practice, sometimes analytical models are available to guide testing. In other cases they are not available, but a test-based model could be derived from the actual hardware. Early on, the CoP listed four research Themes to address the principles of SDT (see above) and what follows are data and analysis that indicate the value that could be added with successful research to address the 3 prime technologies identified in the first paragraph of Part 2.

3. Evidence from the Dynamics Testing Questionnaire Supporting the Prime Technology Areas

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The members of the Smart Dynamics Testing (SDT) Community of Practice took part in a survey to reveal what are the community's current common practices with the aim to inform a strategic plan. The results of the survey reveal what are choice opportunities to advance testing capabilities. The results also consider the broad impact that these advances can have across all members of the community. Additionally, these areas are particularly susceptible to advances under the philosophy of smart dynamic testing.

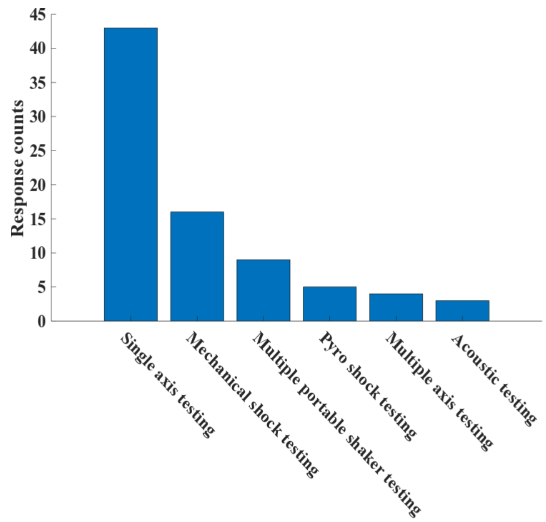

Figure 1. Extent of different test types application across the Community

The smart dynamic testing questionnaire was circulated among various government and industrial organization and the main outcomes are summarized and presented in this section. Basic statistical analysis on the questionnaire results have indicated widespread use and interest in single-axis vibration testing as can be seen in **Figure 1.** Seven of the ten organizations that completed the survey indicated that they use single-axis testing as one of their primary testing methods. Approximately 30% of the type of testing done across the com- munity involved some or the other form of single-axis testing. It should be noted that this might equate to a much larger percent in the volume of actual tests carried out as single-axis. Furthermore, the data also reveals that shock testing is a common choice among the survey respondents.

Boundary conditions are critically important in the process of designing a representative laboratory test, and yet results from the questionnaire indicate that close to 75% of the tests carried out by the community are done using basic fixtures. This is of great concern and an area that Smart Dynamic Testing can aid. Improper matching of impedance at the boundary conditions can void certification tests in laboratory conditions by over or under-testing structures. These results, as seen in **Figure 2,** indicate a choice area of study that can lead to considerable improvements. There are plenty of reasons why there is not more time dedicated to fixture design, but this, nevertheless, provides an opportunity to develop a smart dynamic testing framework that can be implemented in a straightforward manner.

Figure2. Proportion of tests having basic fixture vs those attempting to match field fixture impedance

In addition to supporting the prime technology areas of research, many more detailed insights can be gained from the data. In terms of measurement transducer types, almost 30% of the testing utilizes accelerometers as seen in **Figure 3.** However, the second most popular choice was temperature sensors, which indicate that many of the

respondents conduct test in high temperature environment to closely emulate the operational conditions of the device under test. Future applications of controlled testing will have to more adamantly consider different sensor modalities to assure wide dissemination into the community of practice.

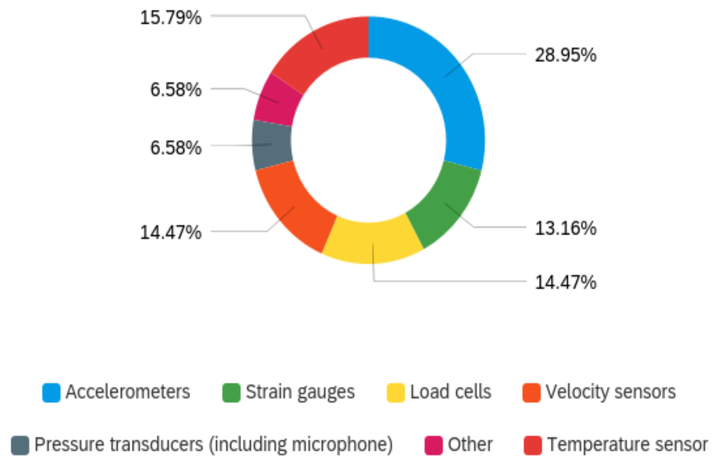

Figure3. Measurement Transducer Types

Further, **Figure 4** illustrates the proportion of tests done in time and frequency domain, which points to the fact that time domain tests are as popular as the frequency domain. This is of particular interest as it informs the community of practice that there is an equal need to deal in both domains.

Respondents have also indicated that albeit most of the tests are tailored to suite customer requirements, they follow standards as more of a guiding principle. In terms of the standards used, MIL standards are more popular as seen from **Figure 5.** What has also been widely discussed by the community members is the need for a thorough examination of proper damage metrics on which to base tests. Although acceleration, in particular, and the use of spectra have been routinely used in the past as the standard to meet, there is an opportunity to delve into damage metrics that can more accurately and directly inform damage and testing requirements.

Figure 4. Proportion of tests done in time domain vs frequency domain

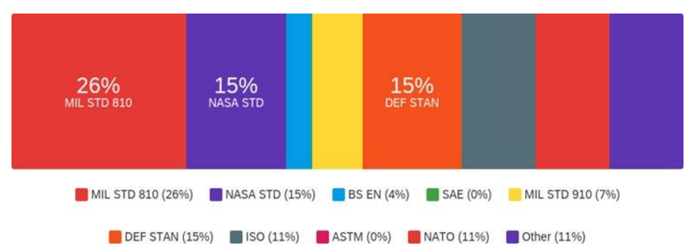

Figure 5. Testing standards

FOOTNOTE: The SDT_CoP Questionnaire has provided a highly valuable set of data on current Structural Dynamic Testing practice. It will provide many other comparisons from further analysis and will be supplemented by future additional surveys of specific issues.